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Worst-case backlog for AFDX network with n-priorities

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Abstract—In most recent avionics systems, AFDX (Avionics Full Duplex Switched Ethernet) is the network used to replace the previously employed point-to-point networks. AFDX guarantees bandwidth reservations by means of virtual links which can be classified with two priority levels. AFDX compliant switches implement output buffers at each switch output port. The stored frames leave each output port according to a fixed priority FIFO policy. Overflow of these buffers must be avoided at all cost to prevent data loss. Although the AFDX standard determines the minimum buffer size dedicated to an output port, the actual length of each priority buffer, is a designer decision.

Previous works address the worst case backlog of AFDX buffers of one and two priorities. In this work we assume an extended AFDX network in which virtual links can be classified into n-priorities and present the problem statement to compute an upper bound on the worst case backlog faced by each buffer of each output port in each switch of the network.

I. INTRODUCTION

In most recent avionics systems, the switched ethernet network AFDX [1] (ARINC 664 Part-7), is chosen to substitute the point-to-point connections of previous avionics distributed systems. Currently, AFDX offers a network bandwidth of 100Mbps and allows for bandwidth isolation among all network traffic by employing the concept of virtual links (VL).

A VL defines a logical path from one source end-system (ES) to one or more destination ESs. The physical route for each VL is statically defined at design time and therefore the switches traversed by each VL are known before run-time. The predictable behavior of AFDX is further ensured by the parameters BAG and S_{max} , respectively bandwidth allocation gap (minimum time interval between the transmission of two consecutive frames of a VL) and maximum frame size associated with a VL. AFDX further allows for the classification of VLs into two priority levels: high and low.

AFDX compliant switches perform store-and-forward. In order to cope with contention for the switches output ports, each output port offers one FIFO queue per priority level. Due to the fixed priority FIFO scheduling at the output ports, switches have to send all frames with high priority before the low priority ones. Considering the non-preemptive property of frame scheduling, a switch cannot abort the transmission of a lower priority frame in favor of a higher priority one.

The AFDX standard specifies the minimum number of frames that must be buffered on the switches output ports. However, the actual output port buffer size for each priority level is left as a design decision and is used in the configuration

phase of the network (section 4.7.3.2 of [1]). Thus, in order to avoid buffer overflow at the output ports and consequently packet loss, the designer must compute an upper bound for the backlog of each priority buffer.

Previous works address the computation of upper bounds for the worst case backlog of AFDX buffers considering virtual links with one and two priority levels. In this work we consider an extended AFDX network where the number of priorities assigned to VLs is unlimited (n-priority levels instead of two) to present the problem statement and the challenges for the computation of an upper bound for the backlog of each priority buffer on each output port of each switch of the network.

II. RELATED WORK

[2] presents how to compute probabilistic bounds on buffer backlogs, based on stochastic network calculus (NC). [3] shows how NC leads to pessimistic results when compared to those achieved by trajectory approach (TA).

In contrast to NC, which considers each VL as a flow, TA analyzes the VL traffic at a finer granularity, accounting for the individual frames of the VLs. In [4] and [5] the authors make use of TA to compute the *e2e delay* for FIFO output buffers with *single priority* and *distinct static priority flows* respectively. [3] computes the worst case *backlog* for FIFO output buffers with *single priority flows*. and extends the previously mentioned works presenting an analysis of the pessimism intrinsic to TA.

Preliminary results for the buffer backlog of AFDX networks with two priority flows have been presented in [6]. We extend this analysis and present the analysis for the computation of an upper bound of the worst case buffer backlog assuming an AFDX network with n-priorities.

III. WORST CASE SCENARIO AND COMPUTATION OF BACKLOG UPPER BOUND

We compute an upper bound for the worst case backlog for any output port buffer in three steps: first, we identify all VLs competing for the output port, second we compute the number of frames of the competing VLs that impact the worst case backlog of the buffer under study, and third we determine the worst case arriving sequence for these frames and compute an upper bound for the worst case backlog.

In this paper we consider AFDX virtual links with n-priorities. Consequently, we assume that n buffers, one buffer

for each priority, exist on each switch output port (similarly to what [1] defines for two priorities).

Identifying the competing virtual links is straightforward: the routes used by the virtual links are computed off-line and do not change during run time. To compute the number of frames from the competing virtual links that impact the backlog encountered by each frame (f_m) with same priority as the buffer under study, we make use of the trajectory approach (TA) [4]. In principle, any other method that provides the number of competing frames can be used in our analysis.

Studying the worst case arriving sequence for the competing frames is the main contribution of this paper towards the worst case backlog computation. We first classify the competing virtual links into three sets: VL^S , VL^H and VL^L , respectively with virtual links of same (sp), higher (hp) and lower (lp) priority than the buffer under study. Then we analyze the impact of each of these sets into each frame of VL^S .

We start our analysis presenting limit values for the worst case backlog upper bound. Further, we expand this analysis to compute a tighter upper bound.

A. Worst case backlog upper bound limits

If we create an imaginary scenario where the frames of the same priority set (VL^S) are the only frames on the network, an upper bound for the worst case buffer backlog of the buffer under analysis ($Buffer^S$) can be computed as presented in [3] and named here as bl_{max}^{onlyS} . Computing an upper bound for the worst case backlog considering all frames (of VL^S , VL^H and VL^L), can only lead a value larger than or equal to bl_{max}^{onlyS} .

The backlog of $Buffer^S$ can never be larger than the sum of the sizes of all frames in VL^S .

Thus, the computed upper bound for the worst case backlog for a buffer of a given priority is limited by:

$$bl_{max}^{onlyS} \leq bl_{max}^S \leq \sum_{\forall f_k^S \in VL^S} s(f_k^S) \quad (1)$$

where the function $s(f)$ represents the length of a frame f .

B. Worst case backlog scenario

Figure 1 presents the arrival of sp and hp frames and how they are scheduled at the output port according to the fixed priority FIFO policy. Figure 1 further shows the backlog of the buffer under analysis ($Buffer^S$). In this figure, frames arrive from four input links and compete for the same output port. Red frames have the same priority as the buffer under analysis (elements of VL^S set) and blue frames are those with higher priority (elements of VL^L set). The impact of lower priority frames will be considered later.

Next we present the meaning of the points in time and time lengths depicted in the figure:

- α : start of transmission of hp frames
- β : end of transmission of hp frames
- θ_{sp} : end of reception of sp frames
- Δ : $\theta_{sp} - \beta$

For the sake of simplicity and without loss generality, we assume that $s(f)$ units of time is the amount of time required to send a frame of length $s(f)$.

The worst case backlog faced by $Buffer^S$ occurs after all sp frames arrive and the access of sp frames to the output port suffers the largest delay. Therefore, we compute bl_{max}^S at θ_{sp} and construct a scenario in which all frames from VL^H and VL^L delay the dispatch of sp frames the longest.

According to Figure 1, the computation of the worst case backlog for $Buffer^S$ can be presented as the sum of all frames in VL^S minus the amount of data transmitted during the time interval Δ , i.e.:

$$bl_{max}^S = \sum_{\forall f_k^S \in VL^S} s(f_k^S) - |\Delta| \quad (2)$$

An intuitive approach to construct a scenario that leads to the worst case backlog of $Buffer^S$, based on previous analysis for single priority AFDX, is to assume that all hp frames arrive before the sp frames (see Figure 1). Further, frames arrive in decreasing order of size within the same set to avoid idle times at the output link [5].

According to equation (2), in order to achieve the worst case backlog for $Buffer^S$, the arrival sequence of the frames should be such that $|\Delta|$ is minimum. Intuitively, in order to compute the shortest Δ (which is equivalent to the longest β since θ_{sp} is constant), we should compute the latest α (α_{max}) and assume that the output link will be busy with all hp frames until β , i.e.:

$$\beta = \alpha_{max} + \sum_{\forall f_k^H \in VL^H} s(f_k^H) \quad (3)$$

as depicted in Figure 1. In this example $\alpha = 70$, $\sum_{\forall f_k^H \in VL^H} s(f_k^H) = 671$ and therefore $\beta = 741$.

However, neither the scenario presented in Figure 1 nor the equation (3) leads to the largest β for every set of frames.

Figure 2 presents a scenario in which one frame of VL^S is shorter than in Figure 1. In this case, the set VL^H remains unchanged and so does the result of equation (3). Nevertheless, in Figure 2, β is larger than 741, in fact $\beta = 771$ due to an idle time of 30 units of time at the output link.

Figure 3 presents a scenario with the same frames as in Figure 2, but a different arriving sequence for the second input link: one lp frame arrives before the sequence of sp frames. Again, the result of equation (3) is 741 but the actual β is equal to 812, even larger than the one of the scenario presented in Figure 2 because of the larger idle time at the output link.

We can conclude that, although the frames arrive in decreasing order of lengths per set (VL^S , VL^H , VL^L), they do not arrive in decreasing order of lengths if we consider all sets together. Therefore some idle time may be present at the output link and consequently equation (3) does not hold. We propose equation (4) to account for this idle time:

$$\beta_{max} = \alpha_{max} + \sum_{\forall f_k^H \in VL^H} s(f_k^H) + idle_{max} \quad (4)$$

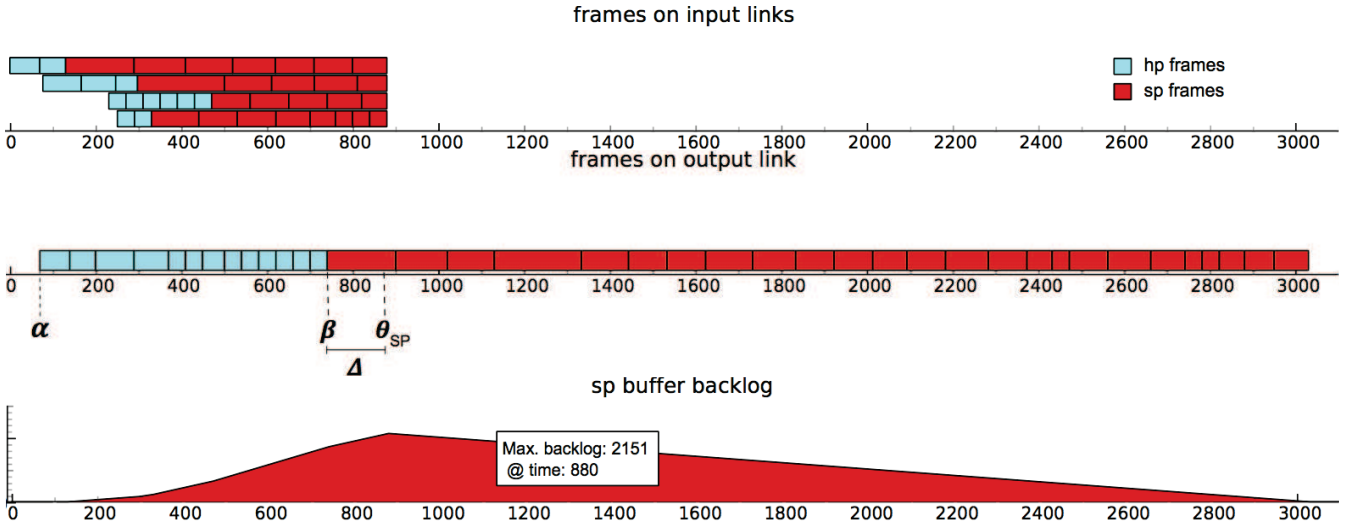


Fig. 1: Intuitive approach for the worst case scenario and computation of the worst case backlog for Buffer^S.

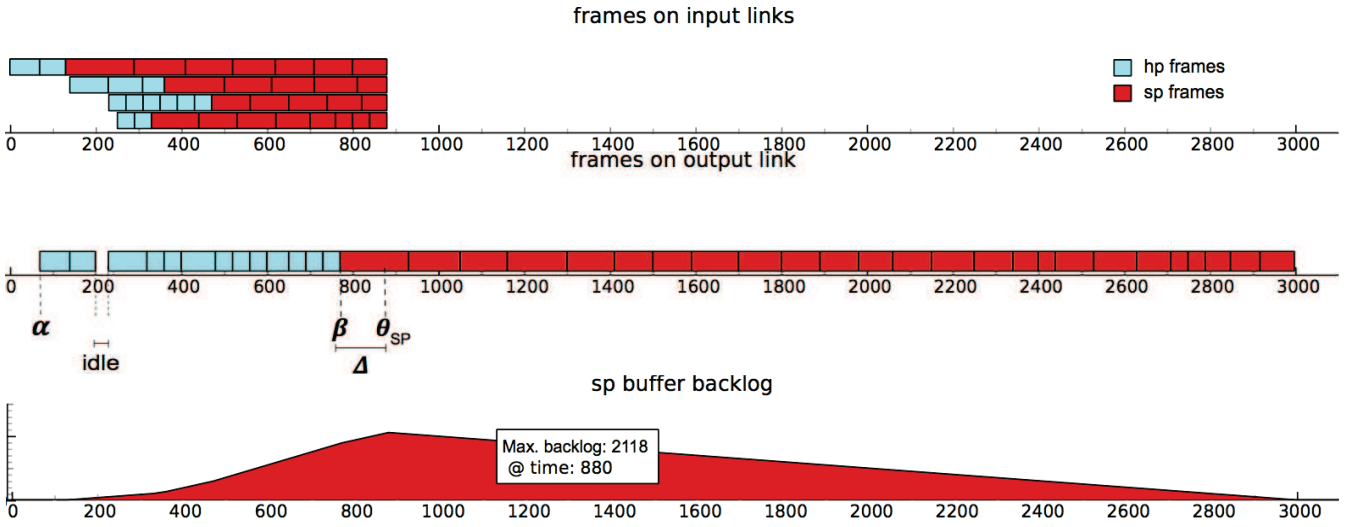


Fig. 2: Small change on previous scenario (one shorter *sp* frame) leads to idle time at the output link and β larger than the one computed by equation (3).

According to equation (4), we must achieve two goals in order to compute β_{max} :

- 1) compute the maximum idle time at the output link due to the non-decreasing arrival order of frames $idle_{max}$.
- 2) compute the latest point in time in which the set of *hp* frames start transmission (α_{max}) such that no *sp* frame is transmitted before α_{max} .

Additionally, we must take into account the impact of lower priority frames.

IV. CONCLUSION AND FUTURE WORK

In this paper we presented the problem statement and the challenges for the computation of an upper bound for the backlog of each priority buffer on each output port of each switch of an extended AFDX network with *n*-priority levels (instead of two).

The challenges to compute an upper bound for the worst case backlog of each buffer, within the limits presented in (1), is summarized as follows:

- prove that equation (4) holds for any sequence of arriving frames
- compute α_{max}
- compute $idle_{max}$
- compute the impact of *lp* frames into the worst case backlog of Buffer^S

Obviously, the computation of an upper bound for the worst case backlog of output buffers for the current AFDX network (with two priorities) is a sub problem of the one presented in this paper and can, therefore, be achieved by assuming $n = 2$.

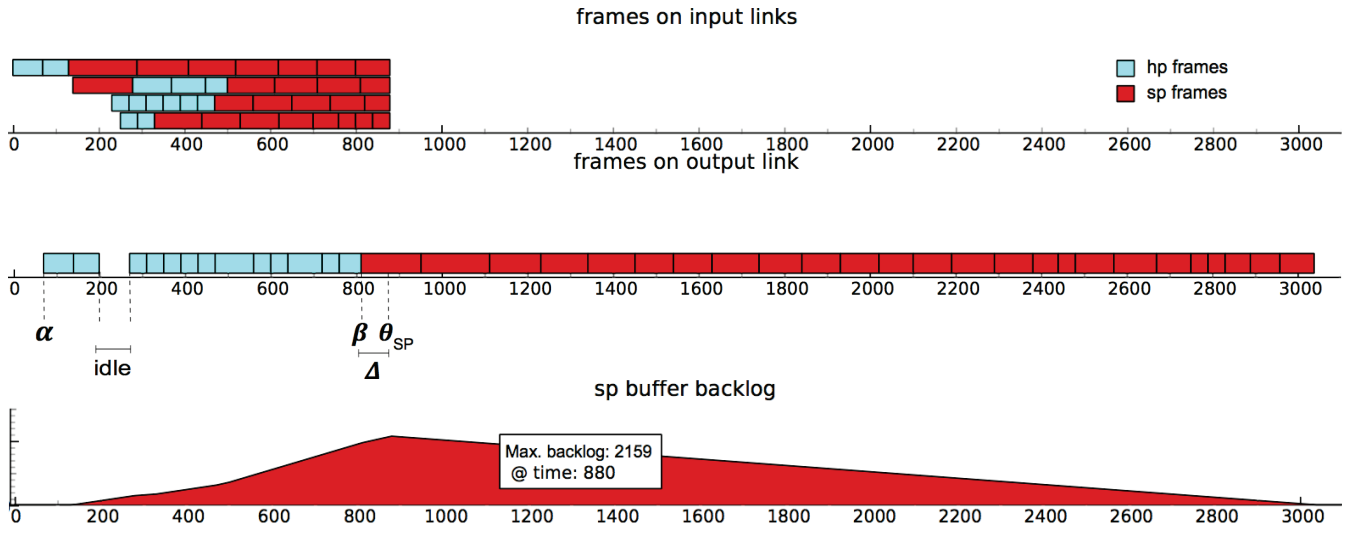


Fig. 3: One *sp* frame arrives first on the second input link leading to larger idle time at the output link and thus larger values of β .

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